

Vector Network Analyzers (VERY) Basics

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SRF Testing Course

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S-Parameters

A scattering matrix relates the voltage waves incident on the ports of a network to those “reflected” from the ports. Note for the output of an amplifier network the “reflected” signal from the output of the amplifier is the output signal from the amplifier.

S-parameters can be used to model multiple devices connected in a more complex circuit.

One can have multiple ports in the network below are examples of two and three port networks.

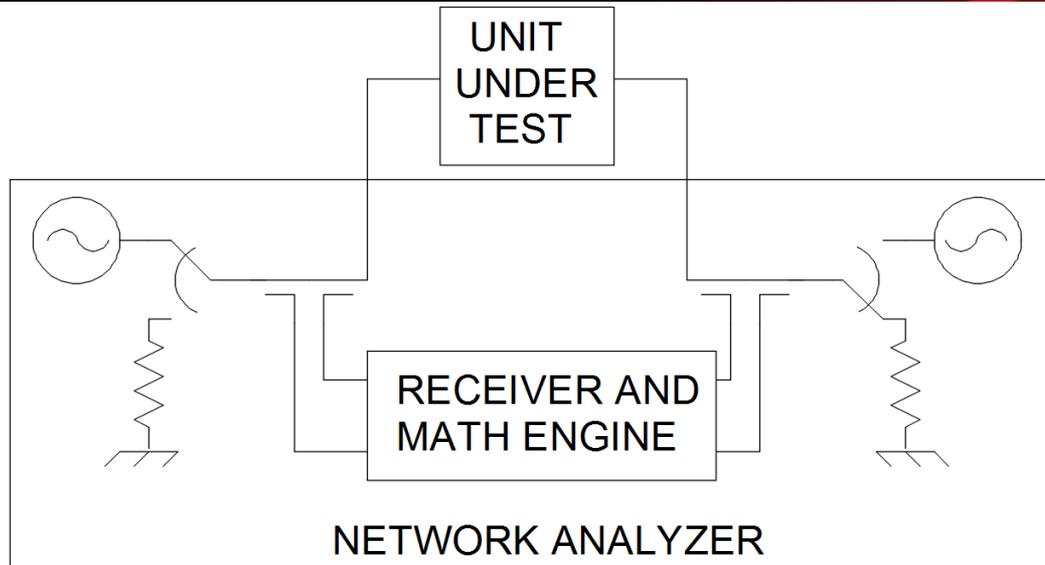
$$\begin{bmatrix} V_{OUT1} \\ V_{OUT2} \\ V_{OUT3} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

$$\begin{bmatrix} V_{OUT1} \\ V_{OUT1} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

To state it slightly differently

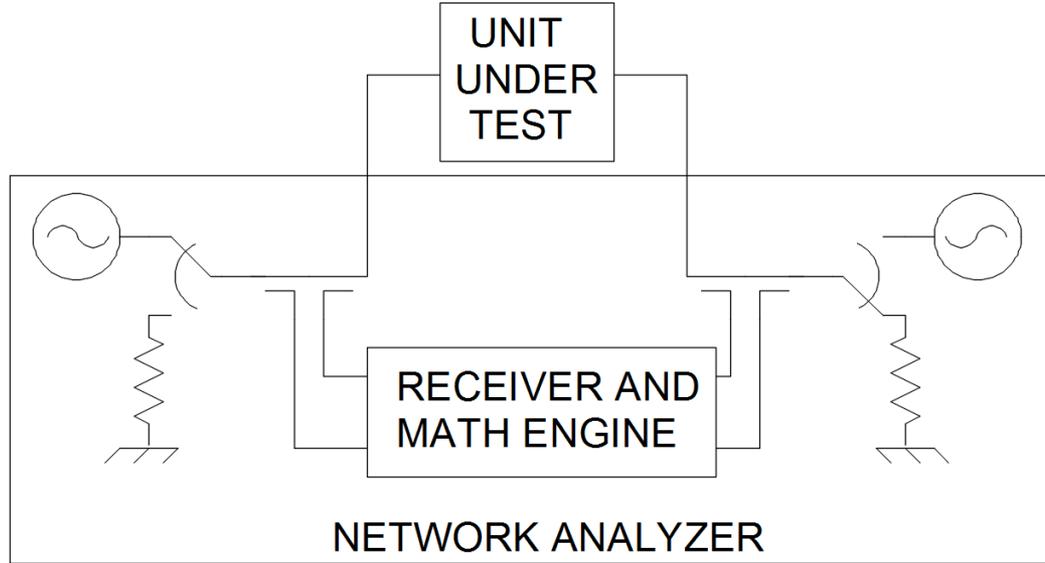
- S11 is the ratio of the voltage emitted from (reflected) port 1 due to excitation applied to port 1.
- S21 is the ratio of the voltage emitted from port 2 due to excitation applied to port 1.

Network analyzer Block Diagram



- Each port has the capability to drive or receive a signal.
- The frequency is generally swept in a discrete number of frequency points.
- The can also sweep power.
- The unit can be set up as a CW source which can make it useful to measure transient behavior of devices as well as to use it as a test source.
- Remember all the parameters for a given measurement are calculated and stored in the instrument, independent of what is displayed.

Network analyzer Block Diagram



- The device has the capability to measure the phase and amplitude for each of the relevant S-parameters.
- Remember if you acquire the data as magnitude of I/Q or Magnitude and phase (not dB) that the signals are in volts not watts.
- Different models behave differently when placed in CW. For instance the 5071 series, by default turns off the RF output at the end of each trace. To stop this behavior one must:
- Select . . . “System” -> “Service Menu” -> Init Src Ctrl [Off]

Calibration of VNA

- In order to accurately determine the S-parameters for a given device a network analyzer has to compensate for.
 - Imperfect internal directional couplers.
 - Imperfect internal loads.
 - Sources with an impedance that is not equal to 50 Ohms.
 - Losses, time delays, gains, attenuations, etc. associated with any cables or devices that are between the VNA and the device under test.
- A calibration is only valid for a given setup including power level, frequency sweep parameters, etc.
- To do this one uses calibration standards. Use of these standards can range from a through calibration where two cables are connected together and the VNA is then used to measure the input to output transfer function of the device under test without worrying about the VSWR (reflections) of the individual ports.
- Some examples are

Calibration of VNA

- WHEN PERFORMING CALIBRATIONS USING A CALIBRATION STANDARDS KIT, ALWAYS MAKE SURE THAT THE MODEL NUMBER IS SELECTED IN THE CALIBRATION KIT MENU. This is especially important with newer network analyzers.
- S21 or S12
 - The most simple calibration is to bypass the device under test, connect the two cables together and select calibrate.
- S11 or S22
 - These are single port calibrations where one applies devices from a calibration kit
 - Open, short and 50 Ohm load are the standards.
- Full two port calibration.
 - A full two port calibration is required if one wants to fully characterize the device under test normally for inclusion in a circuit model.
 - Apply to port1 and port2, open, short, and load.
 - Connect the two cables together and do a thru calibration.
 - Disconnect the cables and do an isolation calibration.

Using a VNA

- This is where, in an ideal situation, I would provide a list of key strokes for setting up and using a network analyzer. Unfortunately we have several different models and the menus are different. I will address the major ones.
- Frequency, start, stop, center, span are all options.
- Power, this is either a submenu of the “menu” button or the “sweep” button.
- Number of points under sweep menu. Can slow down the trace but useful for finding narrow resonances.
- Average can average the values to gain accuracy.
- IF bandwidth (BW) can be found by tapping the average button. This is useful for reducing the noise floor.
- Remember that the BW is effectively a band pass filter in the IF section of the VNA. It must be set to at least 1/3 to 1/10 the bandwidth of the device under test in order to accurately measure the bandwidth.
- Sweep time. Generally this is driven by the bandwidth. However, you can have problems with devices that do not respond as promptly as necessary when switching frequencies and you may need to slow down the sweep in order to improve the accuracy.



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